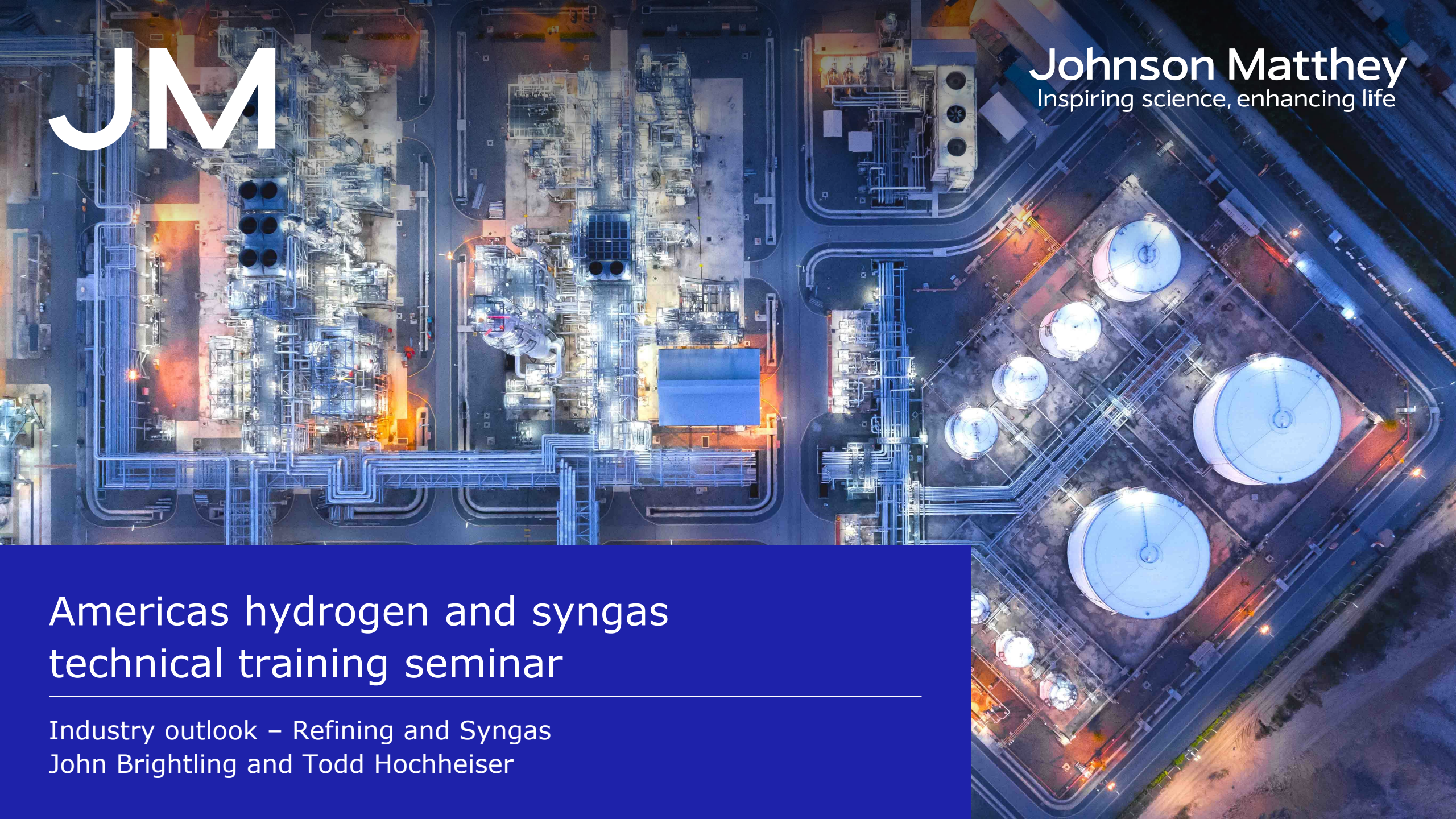

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Americas hydrogen and syngas technical training seminar

Industry outlook – Refining and Syngas

John Brightling and Todd Hochheiser

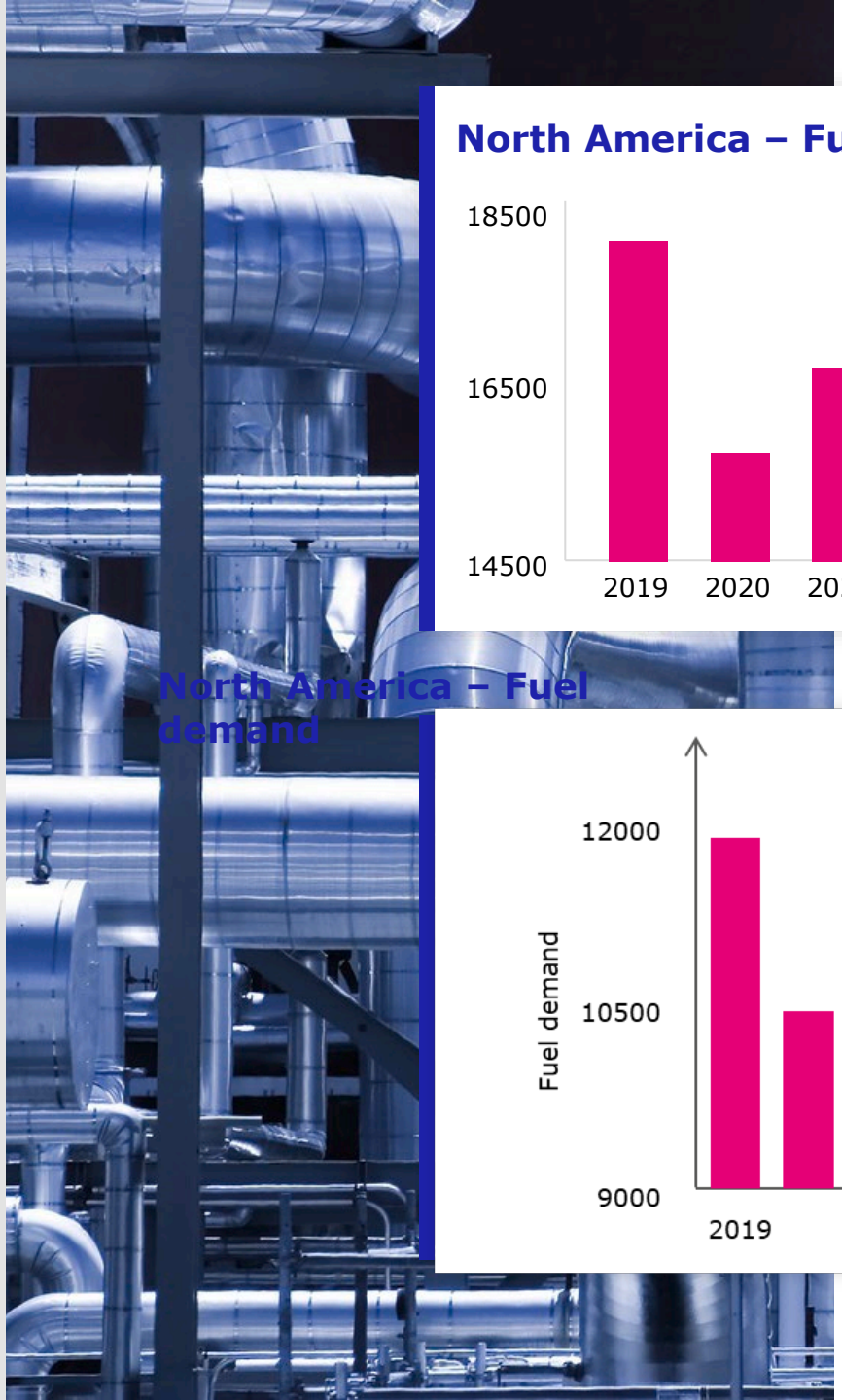
Main drivers affecting refinery margins

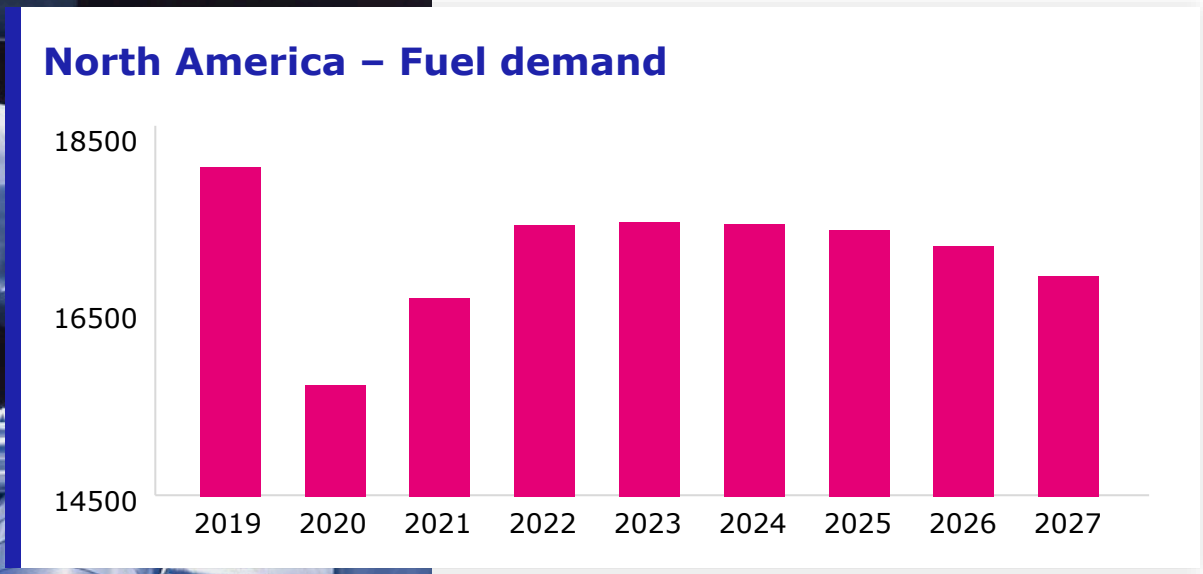
While there are many uncertainties that influence refining margins from a supply and demand perspective, the four biggest drivers are:

US Refiners more buoyant to 2030 than Europe

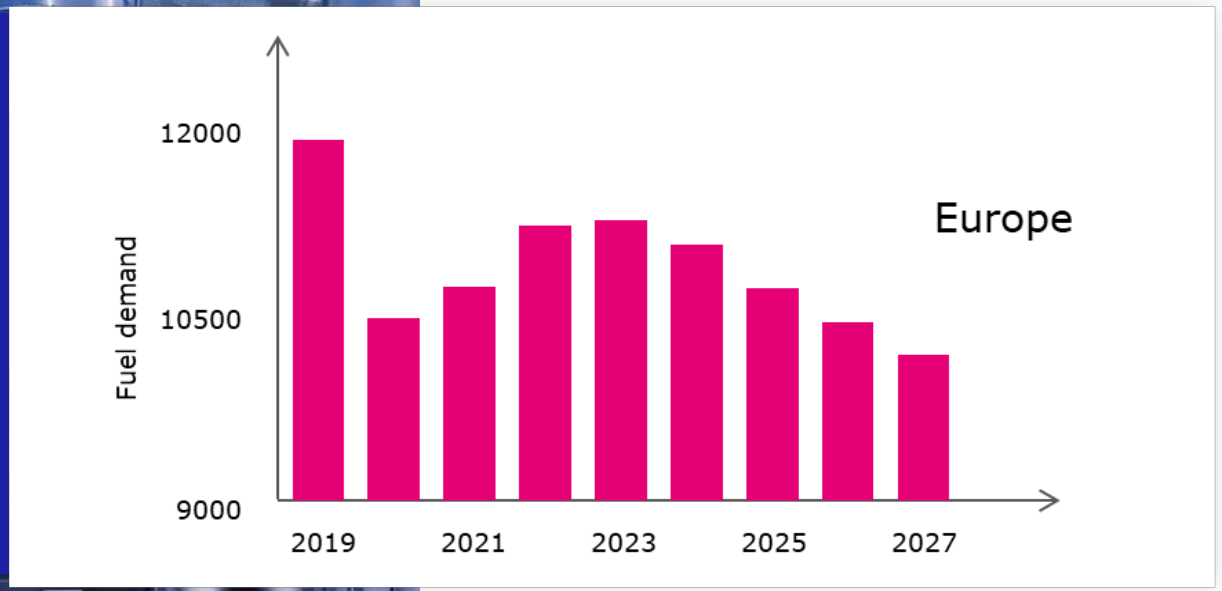
The competitive advantage of US Gulf Coast refiners was emphasized by the Russia/Ukraine conflict, and delivered unprecedented margins

US advantages are driven by its hydrocarbon export position and the higher complexity of its export-oriented US Gulf Coast refineries





North America – Fuel demand



Based on ESAI Energy 2023 data

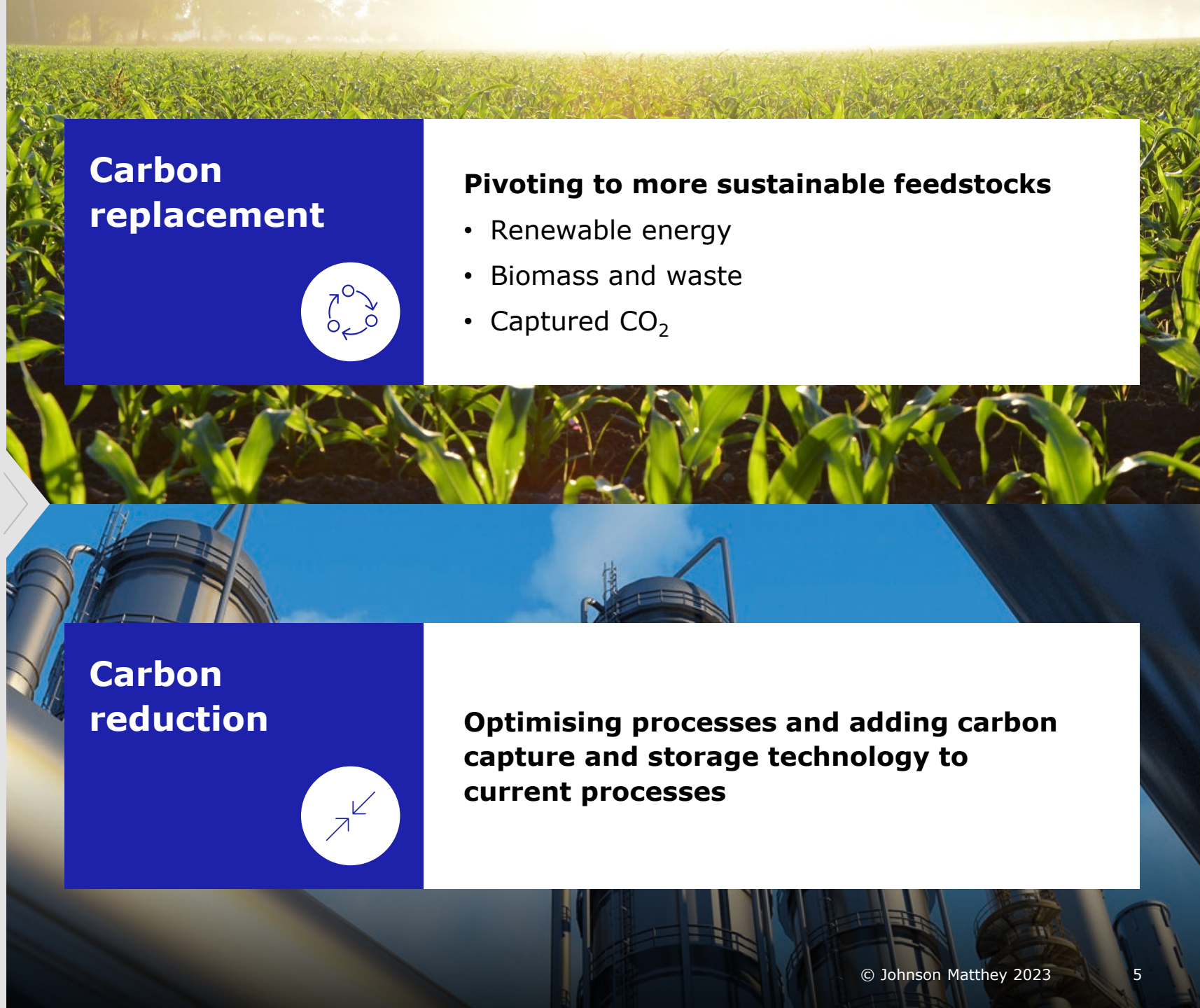
Reliance on fossil fuels maintains grey SMR hydrogen production

- While global GHG is being curtailed reliance on fossil fuels still high at 80%
- Incentivizing production efficiency for decarbonization provides ability to recover costs – create positive business cases
- While not returning to 2019 fuels demand, currently >90% of that demand in US and >85% in Europe projected
- 70% grey hydrogen maintaining through 2030

Source: Baker Hughes – McKinsey

The two pillars of decarbonisation for the chemical and energy industries

The chemical industry is the third largest industrial source of GHG emissions



Carbon replacement

Pivoting to more sustainable feedstocks

- Renewable energy
- Biomass and waste
- Captured CO_2

Carbon reduction

Optimising processes and adding carbon capture and storage technology to current processes

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Regulatory environment and incentives support low carbon hydrogen demand

US

Inflation Reduction Act – c.US$370bn clean energy incentives

Tax credits for low carbon hydrogen projects

EU

Legislation puts **renewable and low carbon hydrogen on equal footing** in terms of CO_2 reduction required

China

First long-term plan for hydrogen promoting hydrogen production, infrastructure development and use

UK

10GW of low carbon and **electrolytic** hydrogen production capacity by 2030

Middle East

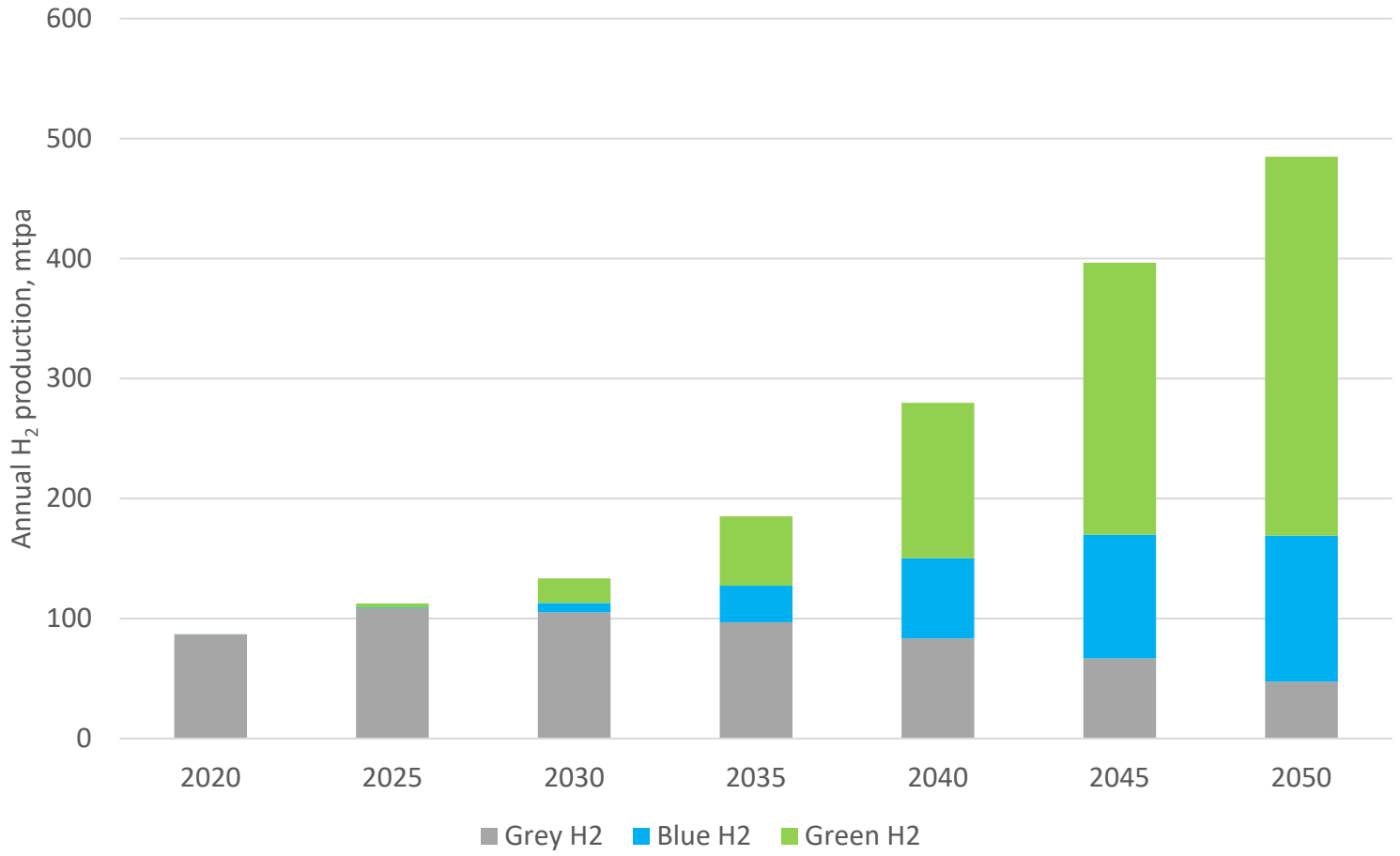
Kingdom of Saudi Arabia:
2.9 million tonnes of low carbon and electrolytic hydrogen by 2030, **4 million** tonnes by 2035

Japan

Target of **12 mtpa hydrogen supply by 2040** (6x today) supported by c.$110bn investment

Source: US National Hydrogen Strategy Report, UK Hydrogen Strategy Report, Argus Media October 2021, Reuters June 2023; EU Renewable Energy Directive, Mercator Institute for China Studies.
Note: Low carbon hydrogen refers to CCS-enabled hydrogen / blue hydrogen.

Growth in the demand for steam-reforming based hydrogen



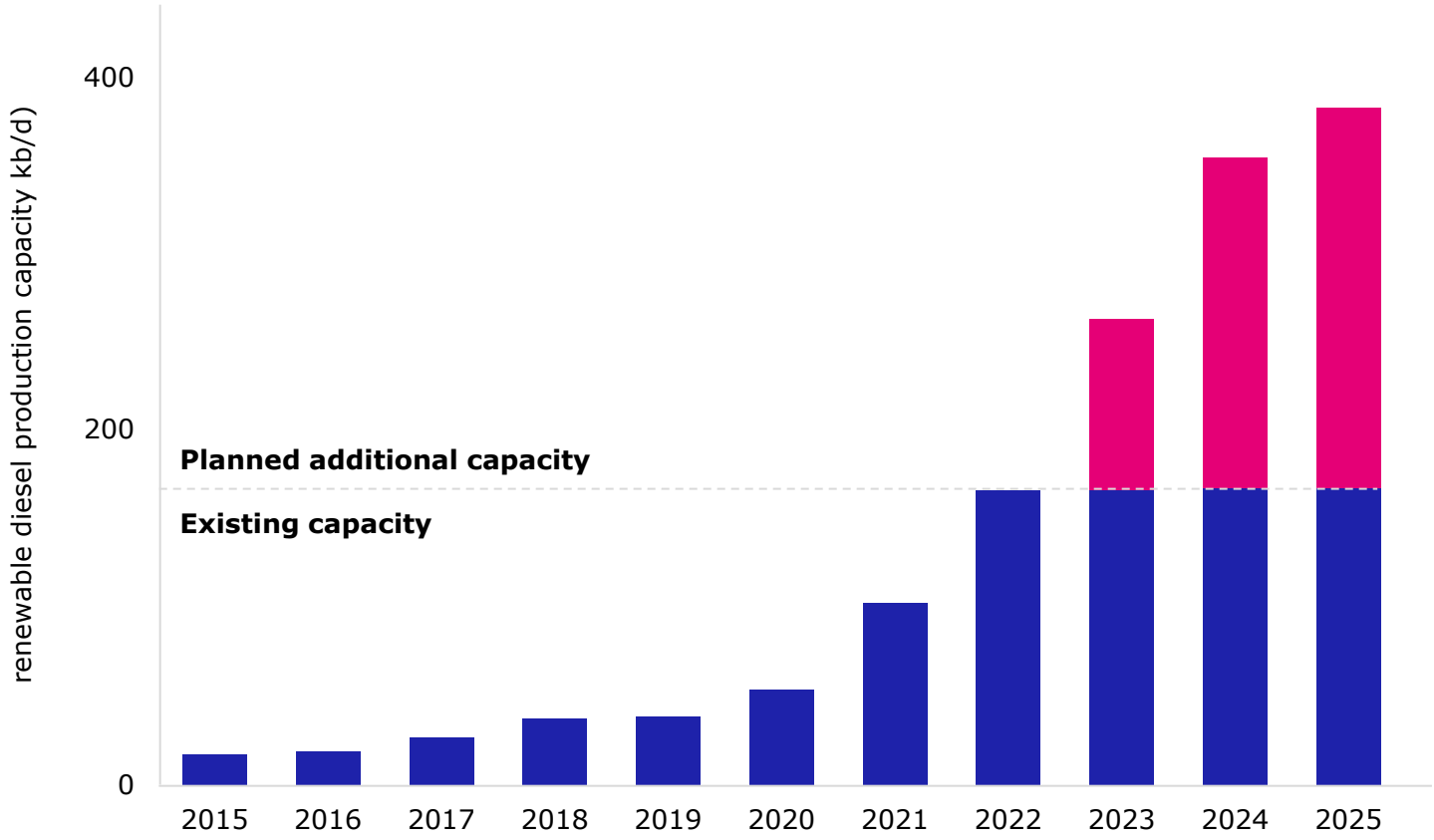
Based on Johnson Matthey's OneJM Scenarios

Grey hydrogen production grows in the near term and is expected to peak in the next 3-6 years, before net capacity removal starts.

While green hydrogen is the end goal, it is recognized that the technology cannot deliver at the scale required and blue hydrogen will play an important role in decarbonizing the industry.

Additional capacity for renewable diesel

Annual existing and expected US renewable diesel production capacity 2015-2025

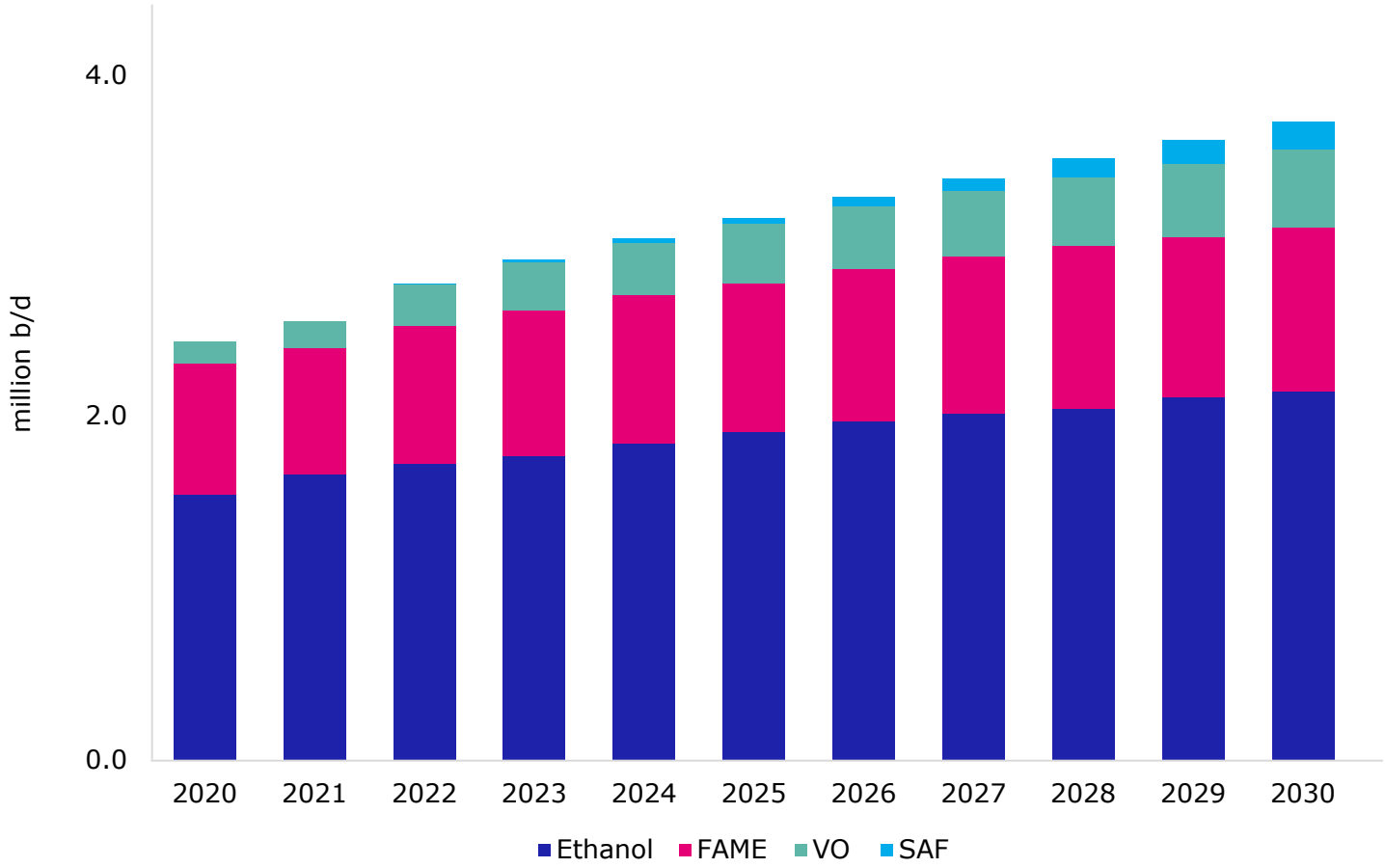


Based on IEA data

Hydrogen lean biogenic feedstock use in refineries is growing

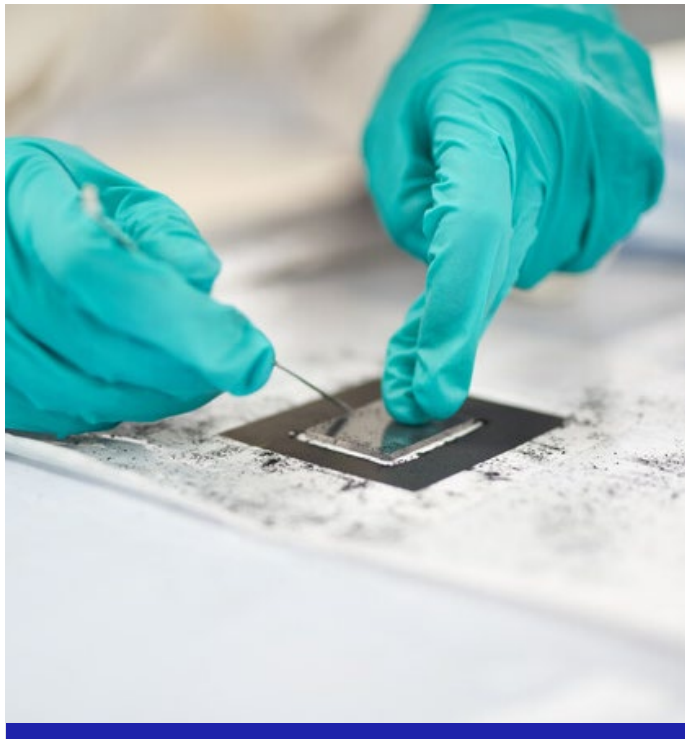
Decarbonization of operations and products are essential investments for the Atlantic Basin refiners seeking long term viability

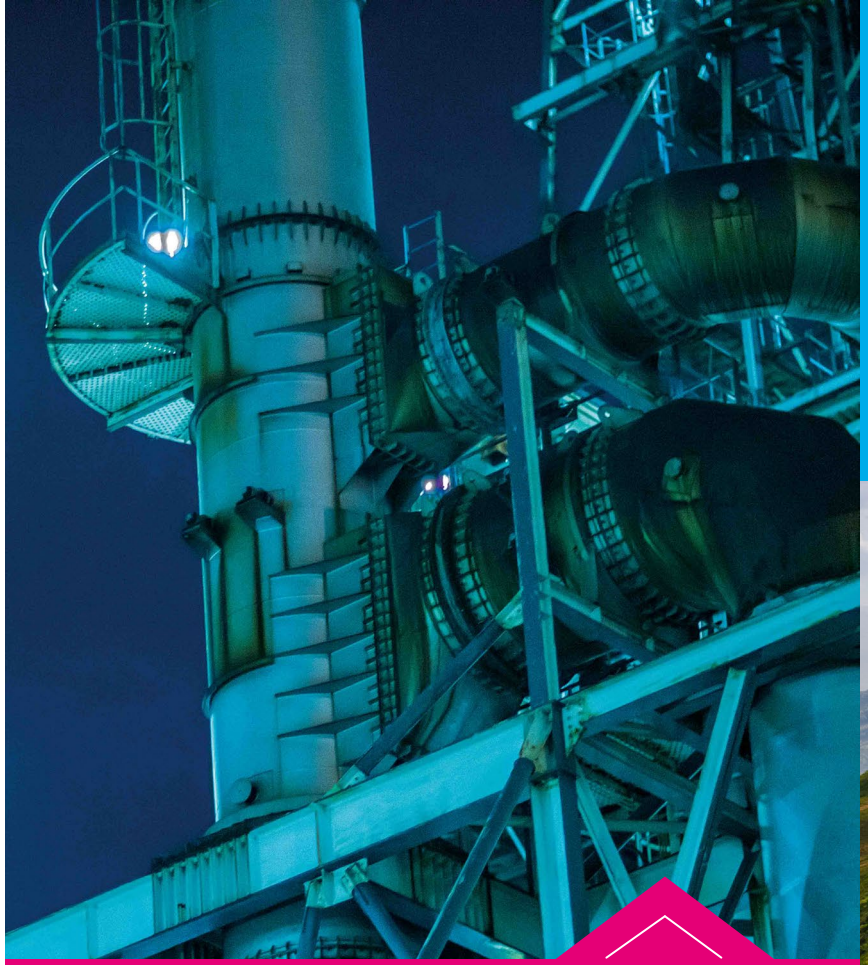
Legislation and industry decarbonization drive demand growth for biofuels this decade, with sourcing low carbon intensity feedstocks being a major source of competitive advantage



Based on IEA data

The role of hydrogen is changing





Today

Most of the on-purpose hydrogen generated at present is in refineries and used to remove sulfur to produce cleaner fuels. Hydrogen is also used in many other industries, including chemicals, glass, electronics and metallurgy

Tomorrow

Hydrogen gas is increasingly seen as the clean fuel of the future for applications such as generating electricity, heating, refining metals, synthetic fuels, upgrading biomass and other uses

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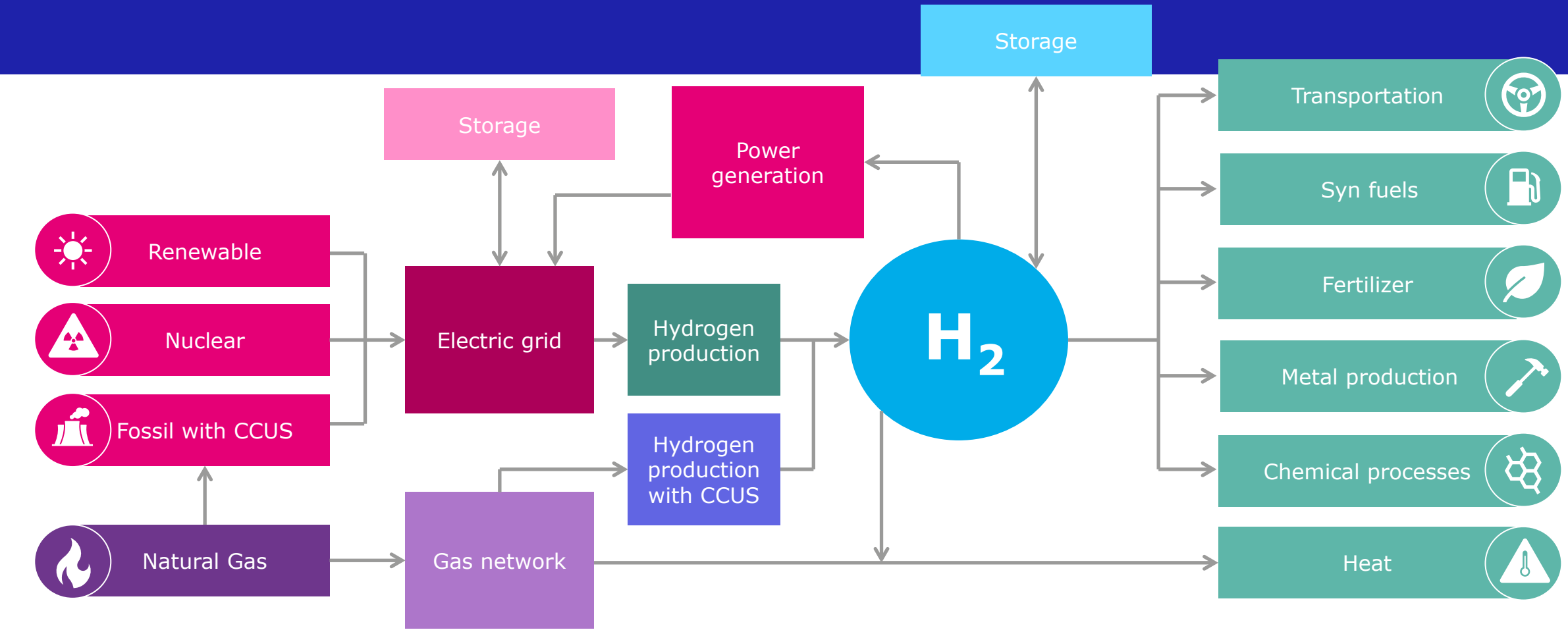
An expanding network for hydrogen



JM's technologies and catalysts are critical to making day-to-day products and fuels

Today
Traditional feedstocks
- Coal
- Natural gas
- Oil

Future
Sustainable feedstocks
- Renewable energy
- Biomass and waste
- Captured CO_2

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Catalysts and process technology

Syngas
H_2
CO
CO_2

Methanol
Formaldehyde
Ammonia
Hydrogen

Other products
Paints and coatings
Polymers
Wood products
Fertilisers
Transportation fuels
Transportation fuels
Natural gas

Industrial and consumer applications

Traditional fuels applications

Syngas building blocks are **c.40%** of major primary chemicals[1]

JM supplies catalyst and/or process technology

1. Source IHS Markit. Capacity of methanol and ammonia as a proportion of total capacity for primary chemicals (methanol, ammonia, major olefins and aromatics).
Note: H_2 – hydrogen; CO – carbon monoxide; CO_2 – carbon dioxide

Ammonia markets

Artsyz'kyi district, Odessa Oblast, Ukraine - panoramio
Анатолий Зубанюк, CC BY 3.0
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New role for low Carbon Ammonia developing strongly

Fertilizer

Hydrogen energy vector

Ammonia fertilizers

Contribution indispensable in food production ~ 80% ammonia currently used as a fertilizer, remaining 20% is used for various industrial applications e.g. polymers, explosives, refrigeration or emissions control.

Low carbon Ammonia

As a clean energy transition fuel shows promise in the context of hydrogen economy, this application currently remains nascent but is gathering strong momentum due to ammonia being highly effective as a carbon free hydrogen carrier

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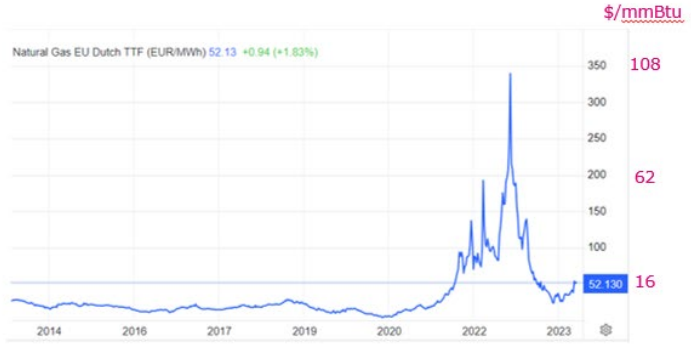
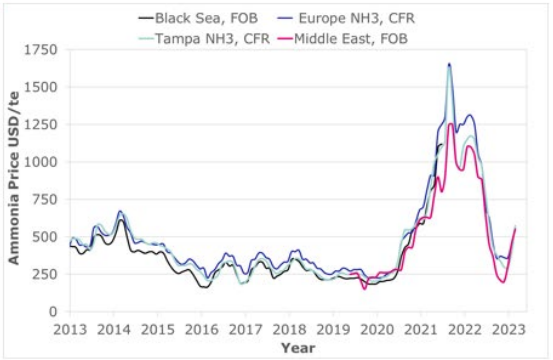
Natural gas costs & ammonia operating rates

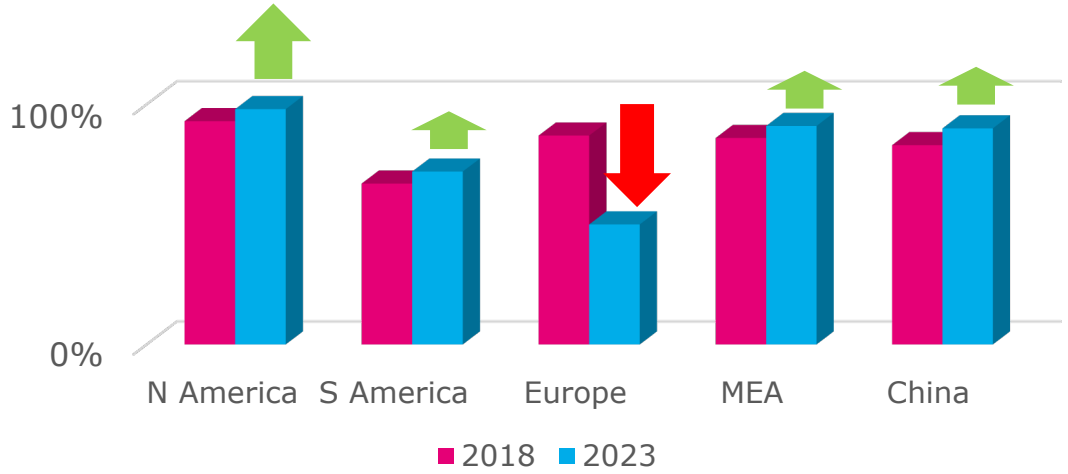
European gas TTF €/MWh



Ammonia prices



Ammonia price follows European gas price



JM estimate of regional Operating Rates

European Natural Gas prices are high region is **highest cost** for production, 95% production cost is gas price making Europe **uneconomic**

During 2022 European price peaking at an equivalent of **$100/mmBTU**

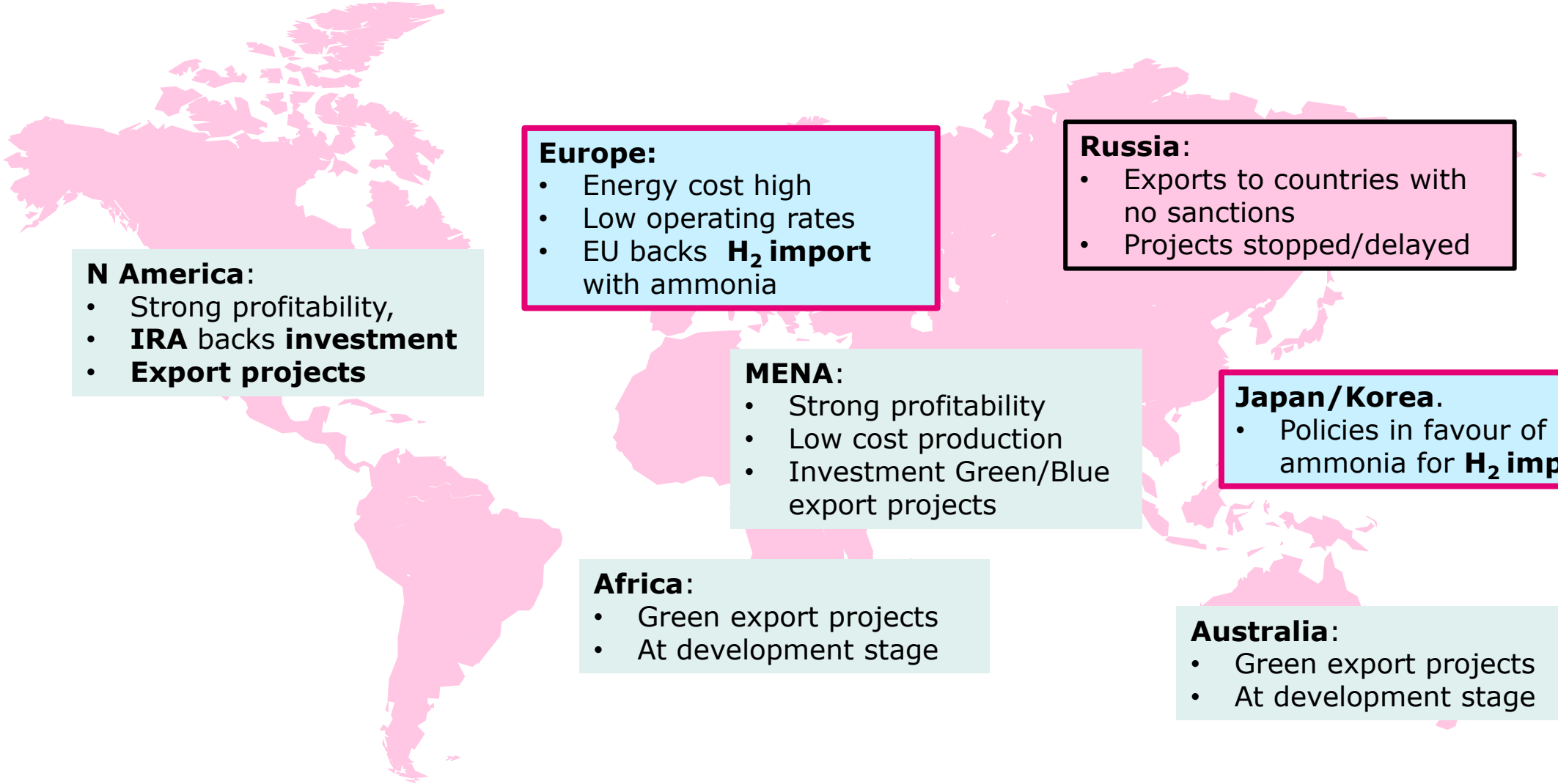
Currently ~ $40-50/mmBTU about three times higher than before Russia/Ukraine conflict.

Makes **Europe marginal producer** with **ammonia prices following** trends in **Europe region gas costs**.

Americas & Middle East are lowest cost and **exporting more**.

Operating rate divergence - **higher Americas & Middle East** and significantly **lower in Europe**

2023 regional drivers and status



N America:
- Strong profitability,
- **IRA** backs **investment**
- **Export projects**

Europe:
- Energy cost high
- Low operating rates
- EU backs **H_2 import** with ammonia

Russia:
- Exports to countries with no sanctions
- Projects stopped/delayed

MENA:
- Strong profitability
- Low cost production
- Investment Green/Blue export projects

Japan/Korea.
- Policies in favour of ammonia for **H_2 import**

Africa:
- Green export projects
- At development stage

Australia:
- Green export projects
- At development stage

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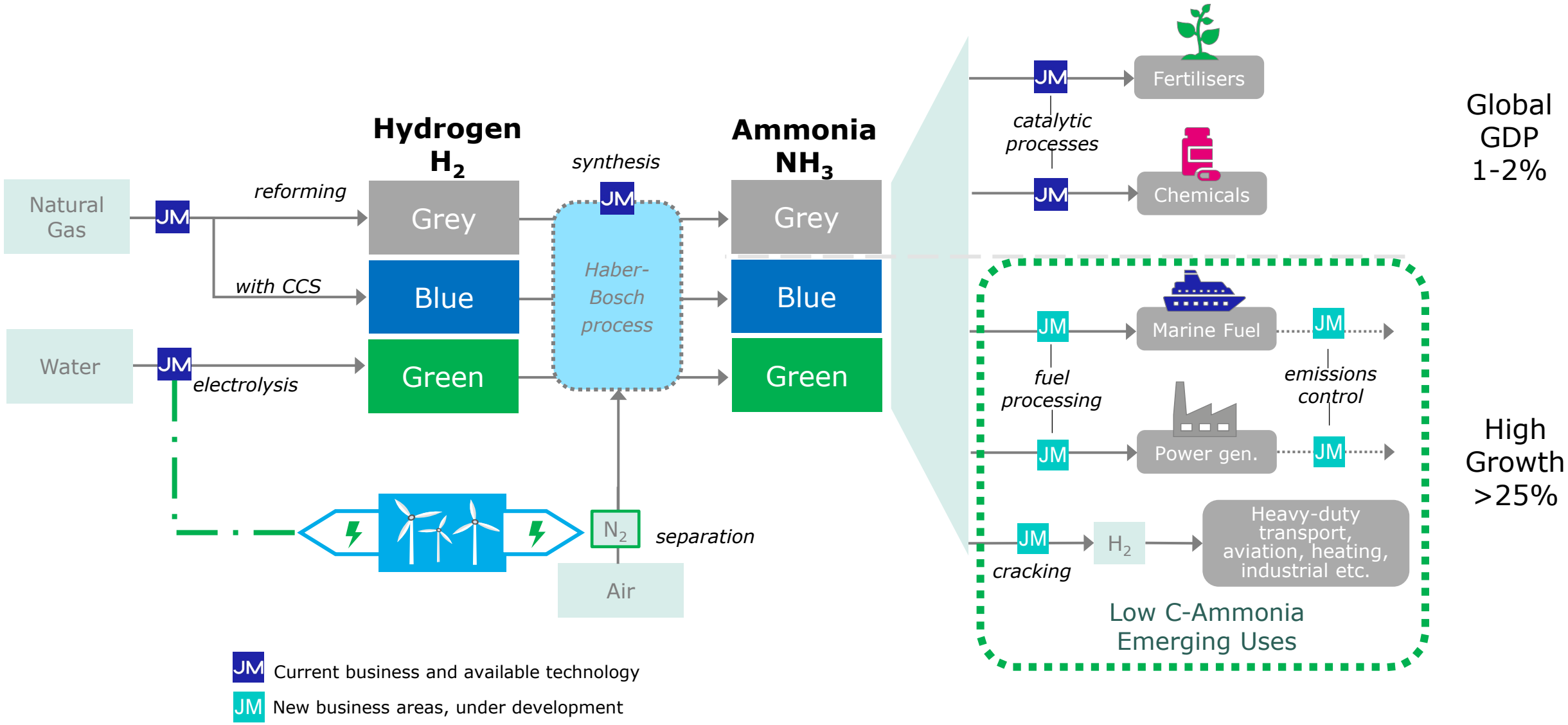
Ammonia's new uses emerging from global decarbonisation efforts



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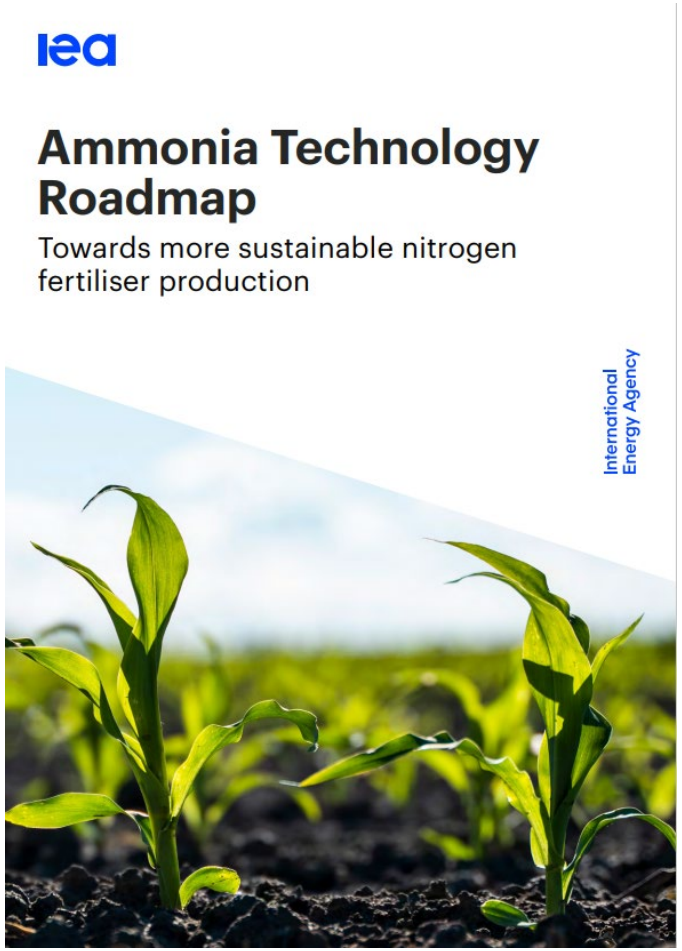
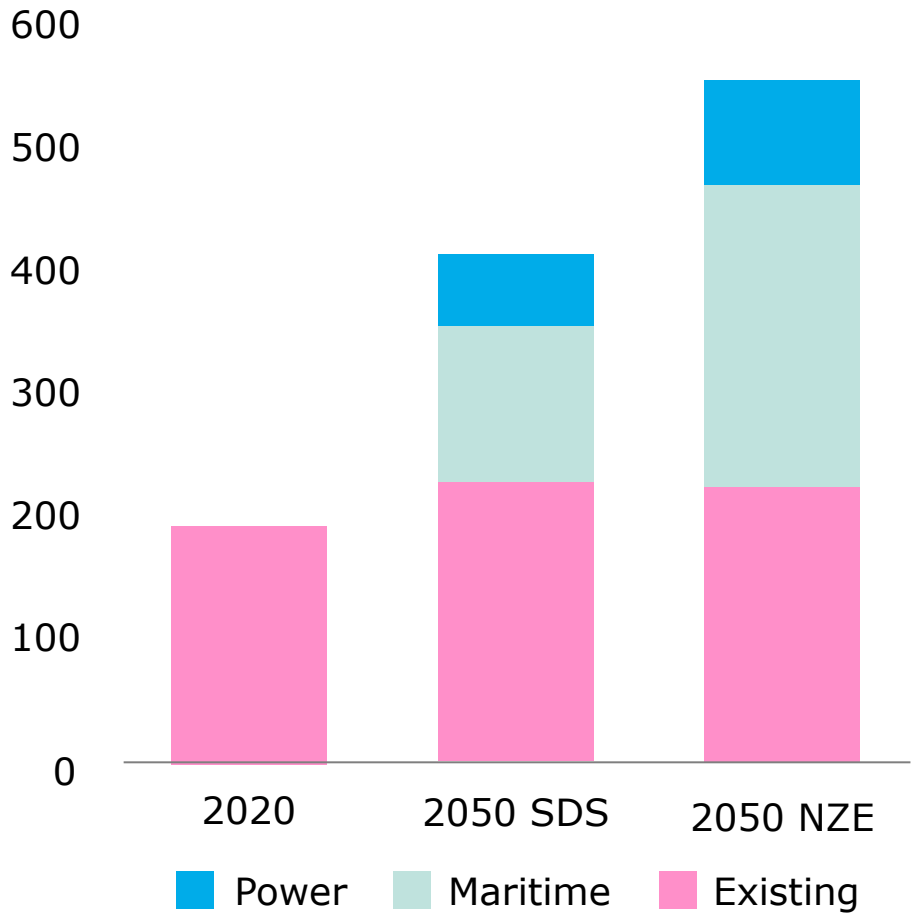
Ammonia IEA report highlights



IEA (2021), *Ammonia Technology Roadmap*, IEA, Paris https://www.iea.org/reports/ammonia-technology-roadmap, License: CC BY 4.0

Future need; more ammonia with fewer emissions



Ammonia interest is high; many players interested

Main energy uses for shipping fuel and power import

Energy Oil & Gas

Power sector

Industrial Gases

Existing players

JM

Announcements for new plant builds aligned with high carbon capture rates

CF Industries and POSCO Evaluating Joint U.S.-Based Clean Ammonia Project and Long-Term Clean Ammonia Offtake Agreement into South Korea

CF Industries and LOTTE CHEMICAL Corporation to Explore Joint U.S.-Based Clean Ammonia Project and Long-Term Clean Ammonia Offtake Agreement into South Korea

REUTERS

Yara and Enbridge plan $2.9 bln ammonia plant in Texas

By Victoria Klesty and Rod Nickel

March 31, 2023 6:00 PM GMT+1 · Updated 7 months ago

Hydrogeninsight

PRODUCTION

A sign on an hydrogen filling pump in California that uses H2 supplied by Linde. Photo: Gado/Getty

Linde to invest $1.8bn in new blue hydrogen plant in Texas, with start-up in 2025

Proman, Mitsubishi sign MoU to develop world-scale ultra low-carbon ammonia plant in Lake Charles (U.S.)

10/18/2023 11:40:00 AM

Proman has signed an MoU with Mitsubishi Corporation to explore building a world-scale ultra low-carbon ammonia facility in Lake Charles, Louisiana. The proposed plant would produce approximately 1.2 million tonnes per year of clean ammonia by

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Mitsui to build $900m 'blue ammonia' plant in Australia

Trading house expects to export 1m tons of the clean-burning fuel to Japan

LOGISTICS

News

Global Energy and Chemical Leaders to develop low-carbon ammonia production project on Houston Ship Channel

Tokyo-based INPEX Corporation, Paris-based Air Liquide Group, Oklahoma City-based LSB Industries, and Houston-based Vopak Moda Houston have agreed to collaborate on the pre-FEED for the development of a large-scale, low-carbon ammonia production and export project on the Houston Ship Channel.

air liquide, chevron, lyondellbasell, and uniper to pursue lower carbon hydrogen and ammonia project along the U.S. gulf coast

Nutrien

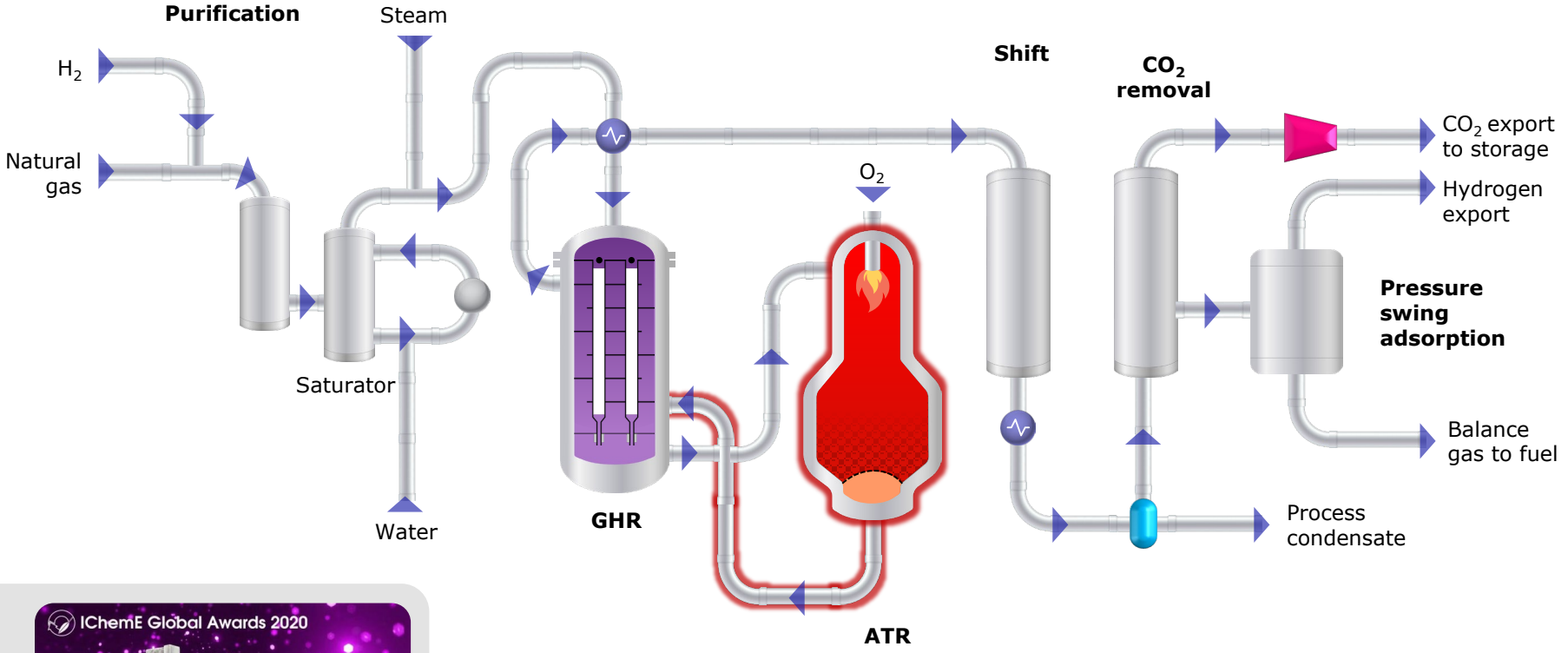
Nutrien Announces Intention to Build World's Largest Clean Ammonia Production Facility

Evaluating existing Geismar, Louisiana site to produce 1.2 million tonnes of clean ammonia annually

SASKATOON, Saskatchewan--(BUSINESS WIRE)-- Nutrien Ltd. (TSX and NYSE: NTR) announced today that it is evaluating Geismar, LA as the site to build the world's largest clean ammonia facility. Building on the company's expertise in low-carbon ammonia production, clean ammonia will be manufactured using innovative technology to achieve at least a 90 percent reduction in CO_2 emissions. The project will proceed to the front-end engineering design (FEED) phase, with a final investment decision expected to follow in 2023. If approved, construction of the approximately US$2 billion facility would begin in 2024 with full production expected by 2027.

The new clean ammonia plant would leverage low-cost natural gas, tidewater access to world markets, and high-quality carbon capture and sequestration infrastructure at its existing Geismar, LA facility to serve growing demand in agriculture, industrial and emerging energy markets. The plant is expected to have an annual production capacity of 1.2 million metric tonnes of clean ammonia and capture at least 90 percent of CO_2 emissions, permanently sequestering more than 1.8 million metric tonnes of CO_2 in dedicated geological storage per annum. The new plant will use auto thermal reforming technology to achieve the lowest carbon

JM's award winning **LCH** process applies our leading expertise in syngas generation to tackle the targets of blue hydrogen/ammonia production



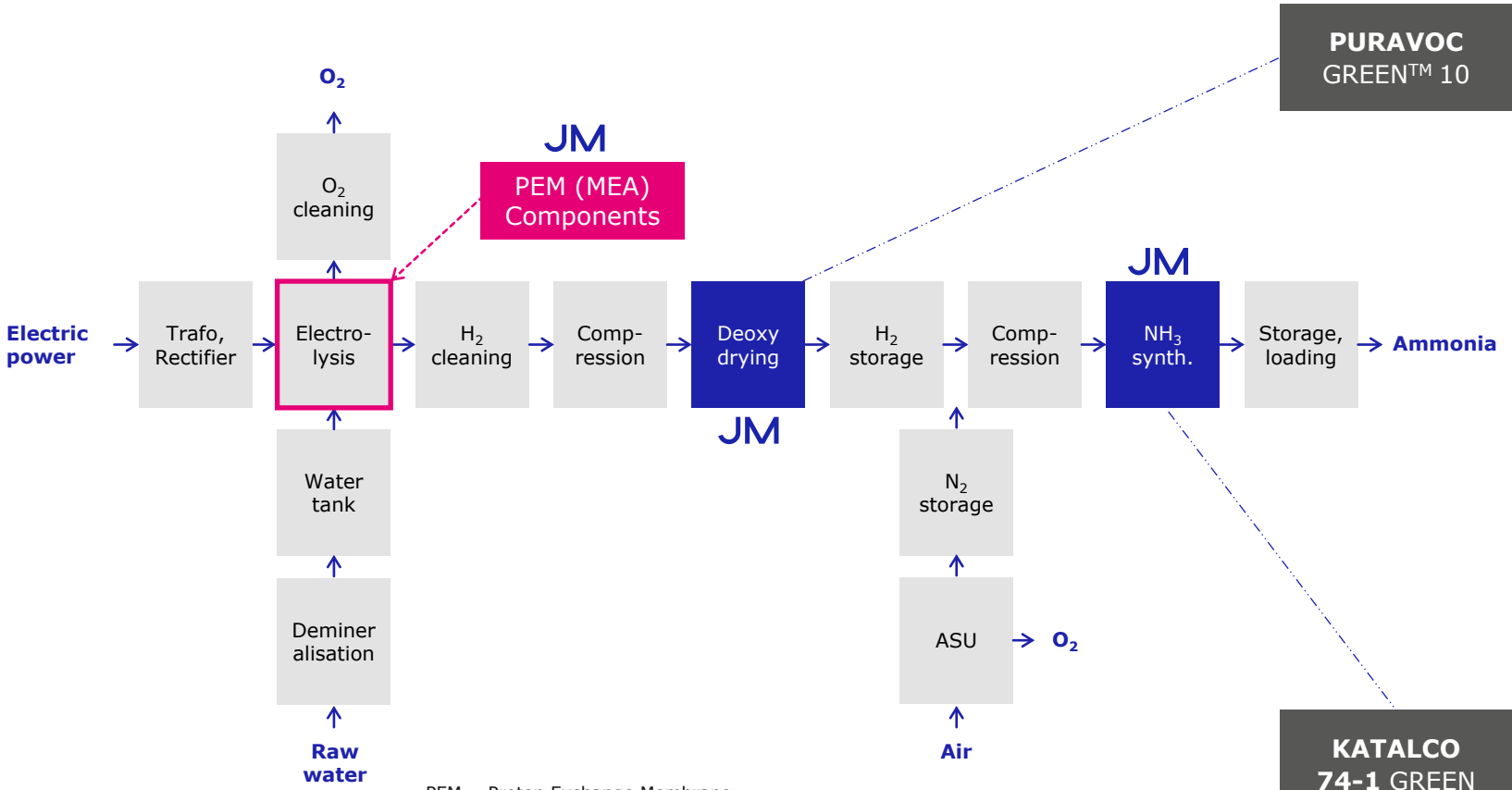
Winner

JM's **LCH** technology enables hydrogen production at lower OPEX and lower CAPEX vs SMR+CCS, saving c.$500m over life of plant

		SMR+CCS	JM LCH™ ATR only	JM LCH GHR+ATR	
Operating costs	 Feedstock required	100%	93% ↓	86% ↓	-$306m[1] vs SMR Over 20 year life of plant
					Lower OPEX
	 CO_2 emitted	100% 90% capture	27% ↓ 97% capture	24% ↓ 97% capture	-$63m[2] vs SMR Over 20 year life of plant
Capex		100%	74% ↓	61% ↓	**Lower CAPEX** -$120m

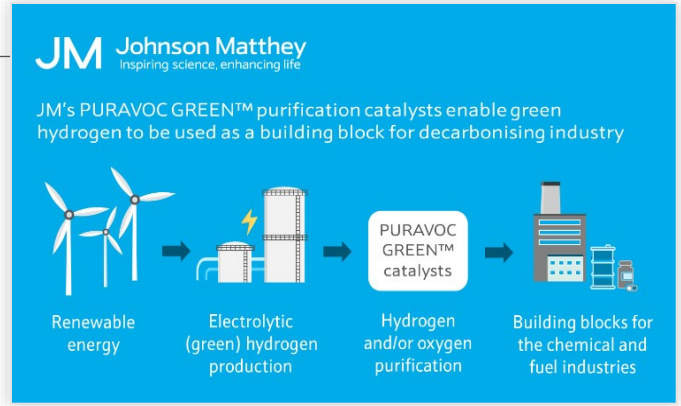
Numbers assume 300 MW hydrogen plant (100k Nm³/hour). These numbers are provided for information and should be considered as indicative. LCH™ CAPEX includes ASU
1. At current EU natural gas cost of EUR7.54/GJ, £12m/year over 20 year life of plant. 2. At current EU carbon pricing of EUR50/tonne, £2.5m/year over 20 year life of plant
SMR data source: IEAGHG Technical Report 2017-02

JM GREEN ammonia products



PEM = Proton Exchange Membrane
MEA = Membrane electrode assembly (Heart of PEM electrolyser)

PURAVOC GREEN™ 10



KATALCO 74-1 GREEN

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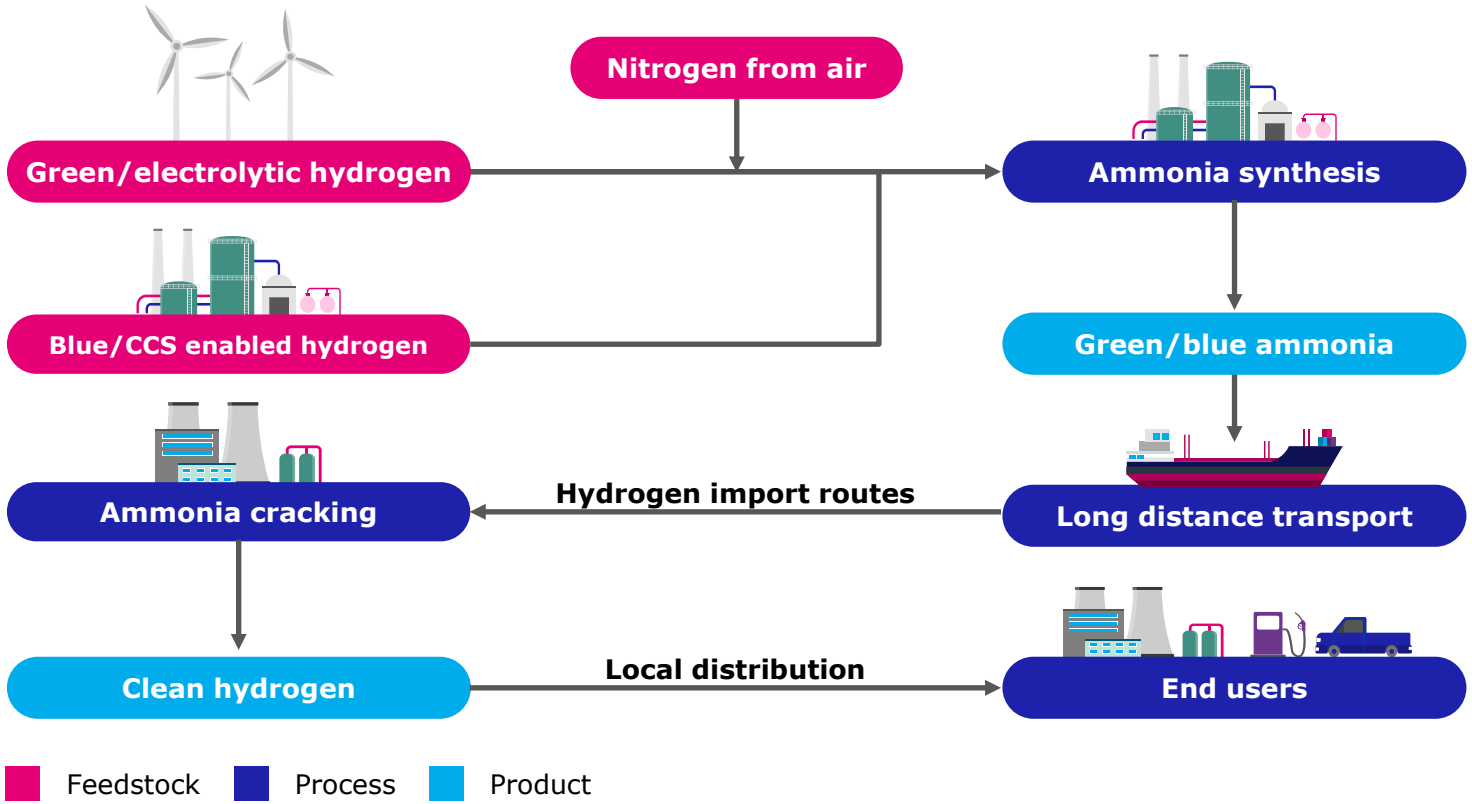
Ammonia cracking is important to open up the broader value chain for hydrogen

Ammonia cracking value chain unlocks a global trade of clean hydrogen

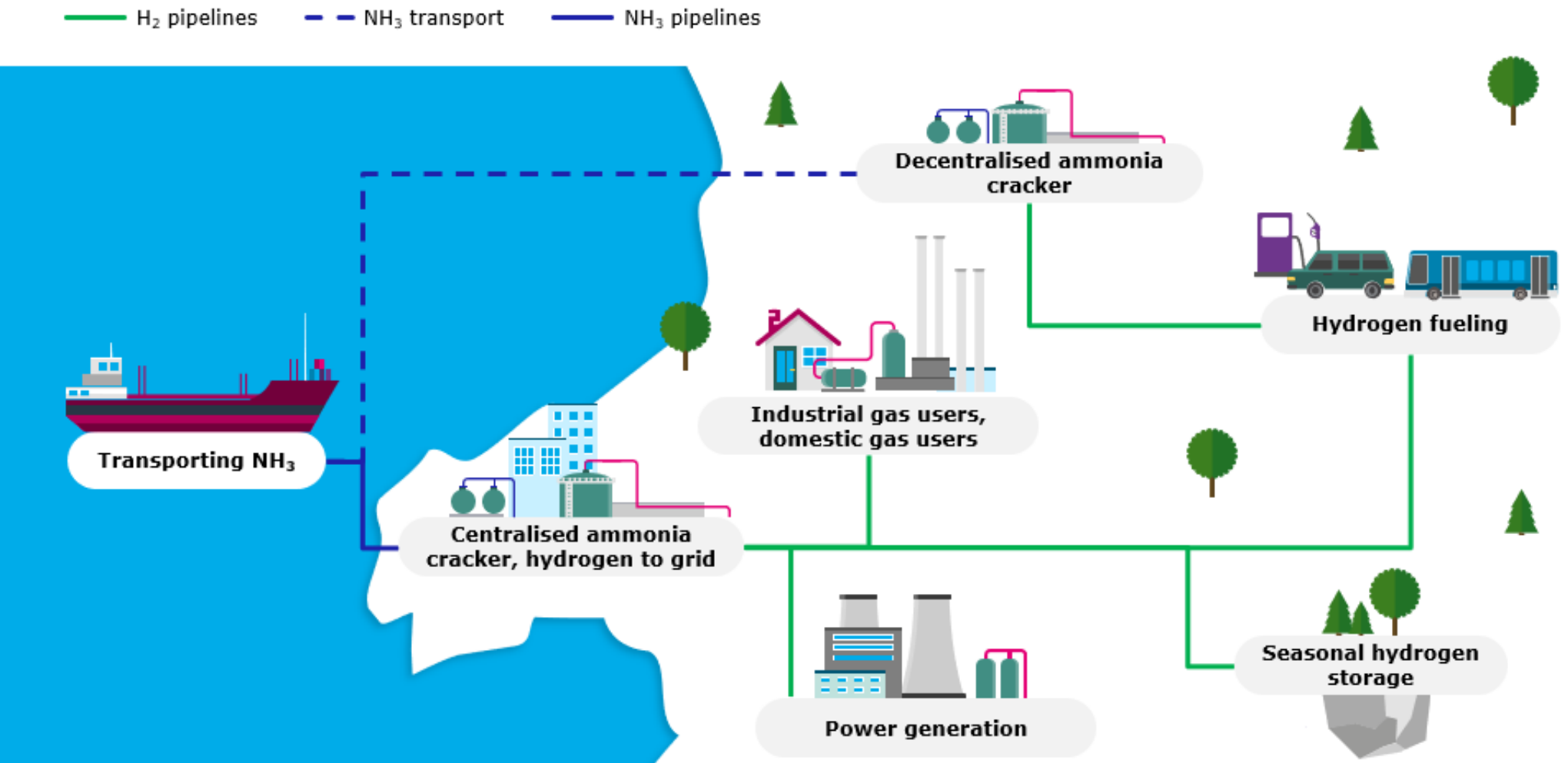


Global clean hydrogen trade creates a **new import market**

Ammonia cracking is key to **enabling clean hydrogen imports**

JM plays a leading role as a **catalyst and technology provider**

Cracking provides a means of converting ammonia back to hydrogen for multiple end-use applications



High purity

Fuel cells

Hydrogen pipeline ↑

Steel, cement, glass ↑

Industrial users ↑

Fired power plant ↑

Low purity

NH_3 – ammonia; H_2 - hydrogen

Summary

- **European** economics mean **rationalisations** likely continue with less **ammonia production,** high cost natural gas feedstock
- **Blue/CCS capacity** investments **very likely in N America**.
- **Exports** from **N America/MEA** will grow, increasing **import pressures** on Europe.
- **Green**
  - Operating units still at modest scales, production growth in renewables rich areas
  - NW Europe needs **H_2 imports** from future Green export hubs to fulfil EU policy of long term energy security and decarbonisation.
- **Ammonia cracking**
  - Reconversion technology from ammonia is major **regional investment focus** in NW Europe and Japan/Korea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